the co-evolution of organizational performance and emotional contagion

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THE CO-EVOLUTION OF ORGANIZATIONAL PERFORMANCE AND EMOTIONAL CONTAGION

R. COWAN, N. JONARD, AND R.WEEHUIZEN

Abstract. In this paper we model interactions between organizational structures, job stress, emotional contagion and organization performance. An organization is modelled as solving problems or performing tasks. Tasks enter the organization and can be addressed by a subset of its members. Organization structure determines which agents can address which problems. Members address the task by applying energy to it. An agent's available energy is determined by his stress level, which is in turn determined by his workload. However agents' stress levels are moderated by social interactions that take place in parallel to the work environment. Organizations can be structured as a group of specialized individuals or as hierarchies of varying depths. We explore the effects of organizational structure and social interactions on performance.

keywords: stress, emotional contagion, social networks, organization structure, productivity
JEL codes: L2, M1, M5, D23

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1. Introduction

This paper uses established results from psychology to examine the interaction of social relationships and work relationships. It is well-established that work can be a major source of an individual's experienced stress, in case of high workload in terms of tasks; and that in turn, an agent's experienced stress affects his or her ability to perform given tasks. The extent to which tasks cause stress is related to the organisational structure, which determines what happens with changes in the flow of tasks. It is also well-established that social interactions can both increase and decrease the stress level of the individuals involved in them. In the model we develop below, we introduce stress dynamics operating both through a social network and through a work network to examine the interplay between organizational network structures and social network structures when job performance affects and is affected by an individuals' stress levels, and when stress levels affect and are affected by social interactions. We are interested in how the performance of different organizational structures is affected by the presence or absence of social interactions. The paper presents a numerical model of interactions over a social network which interacts with intra-organizational interactions through the stress of individuals. The model is built on two parts: the social dynamics are based on well-established results from the social psychology research on stress; organizational behavior is represented by a simple version of the garbage can model of Cohen et al. (1972).

There are many possible ways of describing the structure of an organization: using its organigram; work flow structures; internal communication structures and so on. One simple approach, as seen for example in the garbage can model is to describe the firm as an organziation that solves problems, or equivalently performs tasks. Successful firms will be those that adequately perform either many, or high value (or ideally both) tasks. The internal structure of the organization can then be characterised and formalised in terms of the degree to which responsibility and hence problem-solving capacity is distributed. . Any firm has a wide variety of tasks to perform, ranging from changing light bulbs to fending off hostile acquisition attempts. Different people in the firm have different types of tasks in their remits. At one extreme, in a specialized firm, we could think that each person is responsible for exactly one type of task. At the other extreme, in a team, everyone is responsible for every task, and in an extreme or complete hierarchy, the top person is ultimately responsible for all tasks, as we move down the hierarchy each person is responsible for fewer tasks than his "boss", with the bottom person responsible for only one.

How do different organization structures perform in terms of solving problems? What is the effect of organizational structure on stress levels? How is the performance of different organizations affected by the stress dynamics arising from social interactions? We turn now to a discussion of results from psychology regarding stress dynamics arising both from the work environment and from social interactions.

2. Workload, stress and performance

One of the best-known models for the relationship between workload and stress is the Demand-Control Model (Karasek 1979). In this model work stress primarily arises from the structural or organizational aspects of the work environment, and the extent to which these lead to discrepancies between demands and the ability to deal with them.

Faced with high levels of demands and a lack of control over decision-making and skill utilization, the associated arousal (stress) cannot be channelled into an effective coping response. Unresolved strain may in turn accumulate (Karasek and Theorell 1990) and, as it builds up, can result in anxiety, depression, and physical and mental health problems. High job demands in combination with poor or lacking job resources preclude actual goal accomplishment, which is likely to cause failure and frustration. In its turn this may lead to withdrawal from work, and reduced motivation or commitment. Reducing commitment can be an important self-protection mechanism that may prevent exhaustion.

It should be observed that in the basic demand-control model, more control over the job allows higher demands to be dealt with. However, control itself also takes effort. Planning, regulating, (self-)managing, decision-making, autonomy - in other words, high control - is in itself demanding, and can result in additional stress.

The physiological role of the stress response is to activate the agent to deploy his resources to deal with emerging demands (e.g. Seyle 1956; Karasek 1979). Stress activates coping behaviour, which, when effective, reduces or eliminates the stressors. In a well-known strand of social-psychological research, the relationship between stress and performance has the character of a resource model. In information processing and decision-making, human actors make use of a scarce resource. In Kahneman's (1973) study on attention and effort the notion of 'cognitive energy' was proposed. Experimental research showed that there was a limited factor in the brain which was required to activate and monitor information processing structures, thereby determining the speed and quality of cognitive performance. The provision and allocation of the limited cognitive energy resources is determined by arousal, which is a measure of importance of a certain task, and thus a regulator of cognitive effort. Kahneman's idea of a limited reservoir of mental energy states that the more arousal, the more energy is mobilized to deal with tasks, and the higher the capacity for processing information. A limited and rapidly consumed cognitive energy pool will set the limits of task performance and will constrain coping ability.

Cognitive effort and cognitive scarcity have been the focus of numerous studies in psychology (e.g., Simon 1982), and to some extent in economics (e.g., Conlisk 1996; Herrnstein and Prelec 1991), in particular via the economic work of Simon and Kahneman as basis of notions such as bounded rationality which has become part of the core of economics. Thus, it can generally be put that stress leads to the use of limited cognitive resources for dealing with the stressor (task) and in addition itself consumes part of these limited resources.

3. Social networks and stress dynamics

Stress and coping. Stress activates coping behaviour, which, when effective, reduces or eliminates the stressors. But at high levels of stress judgement deteriorates, behaviour increasingly gets misdirected, and this impedes an agent's ability to produce effective coping (McEwen and Sapolsky; Sapolsky; Liston et al.; Radley et al.).[1]

Stress and social relationships: buffering effects. Individuals involved in social relationships, with a spouse, friend or colleague for example, have a more complex stress dynamic than those who are not. Being in a social relationship is generally beneficial, increasing well-being and reducing stress. Being in a relationship generally absorbs stress and has important buffering effects, which depend on the level of responsiveness of the individuals to each others' needs. Social support from spouses, friends, colleagues and family can help to reduce stress and psychological strains (e.g. Glowinkowski and Cooper, 1985), and is one of the main mechanisms of buffering (e.g. Cohen and Wills 1985; Lepore 1992, Florian et al. 2002).

Stress and social relationships: stress spillovers. Relationships can be beneficial in reducing stress, but they can also be a source of stress themselves. The stress level of one agent, through a variety of pathways, affects the stress level of the other.

Because the internal stress system is non-specific, stress in one domain (work, for example) can "cross over" to another (home) (e.g. Hammer et al. 2005, Stephens et al. 1997). There is some compartmentalization between a person's different roles, so a person can keep different parts of his or her life to some extent isolated, but this is never complete. Thus events in one domain will have an effect in another domain. (e.g. Bolger et al. 1989). But interestingly, stress spillovers from work to home are generally larger when work is high-skilled, when a job carries high responsibility and decision power, and when the worker is highly involved in his or her work (Ginn and Sandell 1997, Glowinkowski and Cooper 1985). This is the first step in the path linking innovation to stress in "unaffected" people.

The second step is that stress also spills over between persons. This phenomenon is referred to as crossover and contagion. *Crossover* refers to the process that occurs when a psychological strain experienced by one person affects the level of strain of another person in the same social environment (Westman, 2001; Westman and Etzion, 1995). *Contagion* is the process by which one individual's mood and/or perceptions seem to "spread" to those in close proximity. Hatfield et al. 1994, survey the large body of empirical evidence on crossover.

Responsiveness. Both social support and stress spill-over are found to follow patterns of affiliation, and the strength of these processes depends on the strength of the affiliation (Gump and Kuliks 1997). In essence, the extent to which relationships have either buffering or spillover effects on stress depends on the intensity of the relationship, but this intensity is itself affected by the stress levels of the actors involved.

The quality and amount of social support a person is able to give is found to be negatively affected by the stress level of the giver (see Procidano and Smith 1997, or Silverstein et al. 1996 for example). Repetti (1989) and Repetti and Wood

[1]In the absence of effective coping, the external stressors will not be reduced or eliminated, stress will increase and overall performance levels will drop, resulting in further stress. Additional stress will then lead to an increase in coping effort but a decrease of actual effective coping (e.g. Hobfoll 1989).

(1997) for example, observe that an increase in a person's stress level diminishes responsiveness to family members. The introduction of stress into a relationship seems to reduce the ability of that relationship to provide buffering.

At the same time, the extent to which spill-over between agents in a relationship takes place also depends on the intensity of the relation between the agents. Again this can be characterised as an issue of responsiveness. Several studies have found that cross-over and contagion effects are more likely to occur when people pay attention to, care for, identify with, or feel responsible for others (for example Benazon and Coyne 2000).

But the extent to which persons are responsive to each other is not constant; it can diminish as stress levels go up. Smith and Zautra (2001), for example, find that interpersonal responsiveness or sensitivity is found to increase reactivity to stressful events, especially those that are interpersonal in nature (see also Conger et al. 1999, Westman et al. 2004). Many empirical studies have shown that the higher a person's stress level, the more maladaptive his relationship with his partner, the less other-focused and the more self-focused his behaviour will become. In other words, the responsiveness of persons to each other is a negative function of their stress levels (see for example Vinokur at al. 1996; Conger et al. 1997; Davila et al. 1997, Davila et al. 2003).

To summarise this section briefly, we conclude the following: the fluctuations of workload induce changes in stress among the organization's agents; agents can reduce stress to some extent by activating coping mechanisms; individual occupational stress (job stress) crosses to other domains and other individuals; social support helps to buffer individual stress; both responsiveness and efficiency of buffering depend on the strength of relationships. In the next section we formalize these relationships and embed them in a model of organizational behaviour.

4. Model

Following the discussion above, the model we develop has two parts: operation of the firm, and social interaction among its employees. Operation of the firm is inspired by the garbage can model of Cohen et al. (1972) (flow of tasks that need to be done), while social interaction is modelled in terms of its effects on stress (buffering vs. spill-over). Schematically, the dynamics of the model are as follows.

The firm is a problem-solving entity. Problems arrive intermittently, and the firm's goal is to have its employees solve those problems. Problems are heterogenous in which agents can contribute to their solution: some problems can be solved by a large set of agents, and some, by contrast, are restricted to a small, specific set of agents. Which agent can solve which problem is captured by a problem affiliation matrix, and solving a problem is done by applying energy to it. According to a fixed energy allocation rule, energy is applied to problems by the agents affiliated with them. When a problem has had enough energy applied to it, it is solved and removed from the firm. At the beginning of each period, every agent is endowed with a basic amount of raw energy, but the energy available for problem-solving is determined by his current stress level: increases (decreases) in stress reduce (increase) his effective energy. An agent's stress level changes by two mechanisms. First, the number of active problems to which he might contribute changes: if it increases, his stress level increases; if it decreases his stress level decreases. Second, social interactions, through buffering and spillovers can change an agent's stress. Agents arrive at work in the morning; changes in the pile of problems on their desks affect their stress levels and so their effective energy levels. According to the allocation rule, they apply energy to specific problems. If problems are solved they are removed from the firm. At the end of the period social interactions take place, which can modify, either up or down, agents' stress levels. The period ends, and "overnight" new problems arrive at the firm. This process iterates for a fixed number of periods.

We develop these aspects of the model formally in the sections that follow.

4.1. **Problems.** A problem p is characterized by a pair $(s_p, \lambda_p) \in \mathbf{S} \times \mathcal{R}^+$, where $s_p \in \mathbf{S} = \{1, \ldots, S\}$ is the problem *type* and $\lambda_p \geq 0$ is the problem *load*. The problem type determines which agents can address the problem via the problem affiliation matrix. This is discussed in Section 4.2 below on firm structure. The problem load is the amount of energy necessary to solve the problem. An active problem is a problem with strictly positive load.

Problems arrive at a rate α per period unless the organization has reached its maximum capacity C. Thus a firm can store at most C unsolved, active problems. If the firm is at this bound, then a new problem only arrives when a problem is solved. In order to solve problems, each period some energy $E_{p,t}$ (possibly zero) is applied to a selection of problems by some (possibly all) agents affiliated with these problems. If the energy applied in a period does not solve the problem, it will bring the problem closer to solution, reducing the energy needed to solve it next period, so the load of a problem evolves as $\lambda_{p,t+1} = \lambda_{p,t} - E_{p,t}$.

4.2. **Firm structure.** A firm employs a set $\mathbf{N} = \{1, \ldots, N\}$ of agents, indexed by n. The organizational structure of the firm can be described by a bipartite network, in which nodes are of two types: problem- or task-types, and agents or employees. Each agent can address, or is responsible for a subset of problem types. We can represent this structure as a problem affiliation matrix, g , in which rows represent agents, and columns represent task types. Each element of the matrix $g_{n,s} \in \{0, 1\}$, indicates whether agent n can address a problem of type s. We assume that this matrix does not change over time.

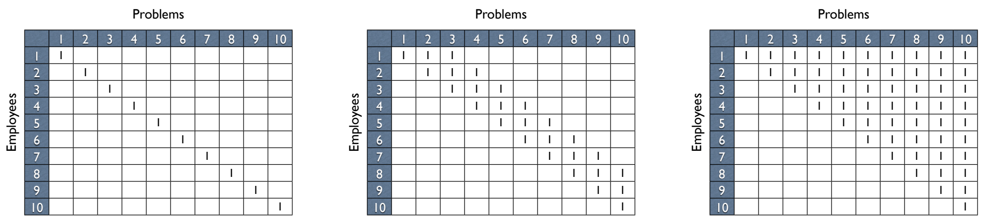

FIGURE 1. Three firm structures: specialized (left) hierarchy, (right), intermediate (middle). A 1 in location (n, s) indicates that agent n can apply energy to problem of type s, i.e. $g_{n,s} = 1$; an empty cell corresponds to $g_{n,s} = 0$.

A specialized organization has a "pseudo-diagonal" affiliation matrix: if the organization is agent-specialized (each agent can address exactly one type of problem) there is exactly one non-zero $g_{n,s}$ per row ($\sum_s g_{n,s} = 1$), whereas if the organization is problem-specialized (each problem can be addressed by exactly one agent) there is exactly one non-zero $g_{n,s}$ per column ($\sum_n g_{n,s} = 1$). If we assume that $N = S$, the number of problem types is equal to the number of employees, then the affiliation matrix of a specialized organization is diagonal: $g_{n,s} = 1$ if $n = s$ and 0 otherwise. This is the maximally specialized structure: each agent is specialized (can address exactly one problem) and each problem is specialized (can be addressed by exactly one agent). The other extreme of configurations we consider is the "complete hierarchy",[2] in which we have an upper triangular matrix: $g_{n,s} = 1$ for $s \geq n$ and 0 otherwise. This is the structure in which agent number 1 in the organization can in principle address any problem, agent number 2 can address all but one problems, and so on until the lowest level agent ($n = N$) who can address only one problem ($s = N$). Figure 1 shows three firm structures. The middle panel is an organization of an intermediate structure, in which any agent (except the last one) can in principle solve a small set of problems and any problem (except the first one) can in principle be solved by a small set of agents. In what follows we consider a family of organizations ranging from the completely specialized organization, through the intermediate organization to the complete hierarchy. In this progression we can see that managerial responsibility deepens: each agent becomes responsible for more and more tasks, and becomes jointly responsible for tasks with more people beneath him in the organization.

4.3. **Individual dynamics of stress and energy in the organization.** Each agent within the organization applies energy to problems. An agent has a "natural" endowment of raw energy, but as discussed in Section 2 above, the agent's current stress level determines how much of this energy is available to address problems. Stress affects energy and thus problem-solving activity. However, problem-solving activity also feeds back on stress: changes in an individual's workload trigger changes in his stress level. Therefore workload (and the related problem-solving activity) and stress coevolve.

Define agent n's stress level at the beginning of period t as $z_{n,t} > 0$. Suppose a problem of type s enters the firm. The stress levels of agents who can address that problem (all n such that $g_{n,s} = 1$) rise to $z_{n,t}(1 + \rho)$. Similarly when a problem of type s is solved and exits the organization, the stress levels of these same agents n such that $g_{n,s} = 1$ decrease to $z_{n,t}/(1+\rho)$. Thus, one problem entering n's backlog followed by resolution of that problem restores the pre-entry stress level of agent n. More generally, if at the beginning of period t a set of k problems involving n enters the firm, the stress level of n increases to $z_{n,t}(1 + \rho)^k$. If by the end of the period the organization has solved $k' \geq 0$ problems involving n, the stress level of

[2]In the literature there seems to be no definitive definition of "hierarchy". What we refer to here is a hierarchy in the sense of who holds responsibility for, or can contribute to the solution of, which task. In these terms, the organization is hierarchical in that each person holds responsibility for all of the tasks of the agents "beneath" him in the organization, in addition to having responsibility for (at least) one not held by any agent beneath him. This might be described as a hierarchy of managerial responsibility.

n is reduced to $z_{n,t}(1+\rho)^{k-k'}$. This is the level of stress of n at the beginning of period $t+1$, i.e. $z_{n,t+1} = z_{n,t}(1+\rho)^{k-k'}$.

Stress dictates how much energy is effectively available to n at the beginning of period t to solve problems. An inverse relation between stress and effective available energy is assumed. We use a very simple functional form: the efficient energy available to agent i at the beginning of any period t is $e_{n,t} = 1/z_{n,t}$. Effective energy and stress change in opposite directions. Although between two consecutive periods the number of entering and exiting problems is the same at the stationary capacity C, the identity of those agents involved in solving problems depends on the random in-flow of problems. So the distribution of stress and available energy coefficients across agents is always changing.

In the structure just described, any problem that an agent can address adds equally to his stress, regardless of how many others can, in principle address it. Thus in the extreme, complete hierarchy, every problem that enters the firm affects the first agent equally. This is a very strong version of "managerial responsibility" — the CEO worries equally about every problem the firm faces, from hostile takeovers to changing light bulbs. This seems unreasonable. Consequently, we examine a modification in which the effect of problem s on agent's stress level is normalized by the number of agents who can address that problem, $\sum_n g_{n,s}$. We capture this with a weighted affiliation matrix w as shown in Figure 2, in which $w_{n,s} = 1/\sum_n g_{n,s}$.

Problems

Employees	1	2	3	4	5	6	7	8	9	10
1	1									
2		1								
3			1							
4				1						
5					1					
6						1				
7							1			
8								1		
9									1	
10										1

Problems

Employees	1	2	3	4	5	6	7	8	9	10
1	1	1/2	1/3							
2		1/2	1/3	1/3						
3			1/3	1/3	1/3					
4				1/3	1/3	1/3				
5					1/3	1/3	1/3			
6						1/3	1/3	1/3		
7							1/3	1/3	1/3	
8								1/3	1/3	1/3
9									1/3	1/3
10										1/3

Problems

Employees	1	2	3	4	5	6	7	8	9	10
1	1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9	1/10
2		1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9	1/10
3			1/3	1/4	1/5	1/6	1/7	1/8	1/9	1/10
4				1/4	1/5	1/6	1/7	1/8	1/9	1/10
5					1/5	1/6	1/7	1/8	1/9	1/10
6						1/6	1/7	1/8	1/9	1/10
7							1/7	1/8	1/9	1/10
8								1/8	1/9	1/10
9									1/9	1/10
10										1/10

FIGURE 2. Three firm structures: specialized (left) hierarchy or complete managerial responsibility, (right), intermediate (middle). Matrix elements $w_{n,s}$ indicate the extent to which a problem of type s affects the stress level of agent n.

In this regime the entry of a problem of type s affects the stress level of agent n as $z_{n,t+1} = z_{n,t}(1+\rho)^{w_{n,s}}$ for all n such that $w_{n,s} > 0$. Similarly when a problem of type s is solved, $z_{n,t+1} = z_{n,t}/(1+\rho)^{w_{ns}}$ for all n such that $w_{n,s} > 0$. This implies that at the end of period t (equivalently at the beginning of period $t+1$), after a set $\{s_1, \ldots, s_k\}$ of problems has entered the organization and a set $\{s'_1, \ldots, s'_{k'}\}$ of problems has been successfully processed, the level of stress of n is $z_{n,t+1} = z_{n,t} \cdot (1+\rho)^{\Delta w}$, with $\Delta w = w_{n,s_1} + \cdots + w_{n,s_k} - w_{n,s'_1} - \cdots - w_{n,s'_{k'}}$. Symmetrically, the energy available to agent n is obtained as $e_{n,t+1} = e_{n,t}/(1+\rho)^{\Delta w}$.

To this point we have neglected the effects of agents' embeddedness in a social network. How individual stress levels are changed through social interactions is described in Section 4.5 below.

4.4. **Energy allocation.** The energy allocation rule of the original garbage can model of Cohen et al. (1972) was simultaneous, and aimed at immediate problem solution. Each problem active in the organization at time t has a current load, the energy needed to solve it, $\lambda_{p,t}$. The garbage can energy allocation rule implies that each agent should apply all his energy to that problem which, of all the problems accessible to him, has minimum load. As a result, during period t, the first problem addressed is p' such that $\lambda_{p',t}$ is the smallest load value for all unsolved problems in the organization. The amount of energy applied to p' is then simply equal to $E_{p',t} = \sum_n g_{p',n,t} e_{n,t}$, which in effect sums the energy of all agents p' is accessible to. This reduces the problem's load to $\lambda_{p',t} - E_{p',t}$. The organization then moves to the next problem closest to resolution, having removed from the set of possible problem-solvers the agents who have just applied their energy to p'. And that process iterates until either all agents have been used, or there are no more problems to be solved by the remaining agents. Then the period ends. Any problem that has had more energy applied to it than its load, $(\lambda_{p',t} \leq E_{p',t})$ is solved, and exits the organization, to be replaced by a new, random problem. Otherwise $\lambda_{p',t+1} = \lambda_{p',t} - E_{p',t}$ at the beginning of period $t+1$ and p', though closer to solution, will need further attention and energy.

The garbage can rule gives priority to immediate problem solution, but has the feature that it could generate considerable waste, as many agents could apply themselves to a problem that needs only a tiny amount of energy to be solved. Consequently, we consider a variation which maintains the original spirit but is not so productive of waste. In the "sequential garbage can", in random order each agent, n, considers the problems to which he has access, and applies his energy to that with the minimum load. Immediately after an agent applies his energy to a problem, the load of that problem is adjusted, so the next agent to make the allocation decision sees a different load for that problem.[3] This rule also focusses on immediate problem solution but by having agents act sequentially instead of simultaneously, considerably reduces redundant effort.

4.5. **Social dynamics of stress.** We assume that agents are located on a social network, and interact only with direct neighbours in that network. Our focus is on the effect of social interaction with members of the organization. Social effects obviously go much beyond the boundaries of the firm, including spousal, family and friends interactions, and broader, even society-level effects. While acknowledging that such effects are at work and can play an important part in the fluctuations of individual stress levels, our focus here is only on social interactions between members of the organization. (For that reason it might perhaps be useful to conceive of these interactions as those that take place around the coffee machine or in the cafeteria.)

[3]There are obviously many possible energy-allocation possible rules. A waste-minimization analogue of the garbage can rule is simply that each agent applies energy to the problem with the maximum load. Naturally this reduces waste but contains the possibility in principle that no problem ever gets solved. One more sophisticated rule, can be seen as a combination of the two sequential rules. Each agent considers the problems to which he has access. If there are problems he can solve, he picks the one to minimize $e_{n,t} - \lambda_{p,t}$. If there are none that he can solve, he minimizes $\lambda_{p,t} - e_{n,t}$ instead. This combines the goals of immediate problem solution and waste minimization. All of these rules produce qualitatively similar results for the issues we analyze below.

The social network can be derived from the problem affiliation matrix. It has a set of vertices $\mathbf{N} = \{1, \ldots, N\}$ (agents' indices in this network are the indices in the organization structure) and a set of edges (ties between vertices) connecting agents who are close to each other in terms of the tasks or problems they are eligible to solve. Specifically, we connect each agent to the three nearest agents on either side along the diagonal. Agents extreme in the hierarchy, such as the CEO or the lowest level workers, have more agents on one side than on the other and so have a smaller social neighborhood than more central agents. The neighbours of n are $n \pm 1, n \pm 2$ and $n \pm 3$, with agents $1, 2, 3, N-2, N-1$ and N having fewer neighbours due to boundary constraints. Then we simply remove a fixed proportion (one third) of randomly selected links from that nearest neighbor structure to generate the social network we use in the model. This social network is kept constant across all problem affiliation matrices. The underlying intuition for such a choice is best seen in organizations of intermediate levels of specialization. There, agents who are close in terms of indices share tasks, and the closer they are the larger the number of shared tasks is. The middle panel in Figure 2 illustrates this well. Agent n has 2 problems in common with agents $n \pm 1$, 1 problem in common with agents $n \pm 2$, and shares no problems with agents further away. It is likely that sharing problems is likely to create social ties. Likely but not necessary by any means, which is why random link removal takes place once the initial structure has been created. Figure 3 shows a typical social network that results from this construction algorithm.

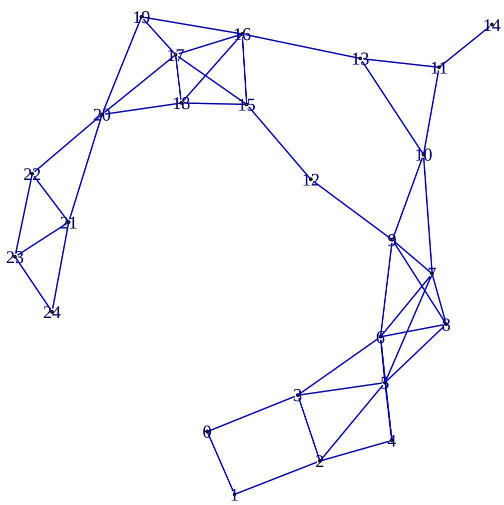

FIGURE 3. A sample social network.

We draw the social stress dynamics directly from Cowan et al. (2011). It consists of three parts: an agent's individual stress reduction through coping; stress reduction through being buffered by other agents; and stress increase through stress spillovers from other agents. For an interaction between two agents n and

m, stress levels evolve as

$$\begin{cases} z_{n,t+1} = z_{n,t} + z - cz_{n,t} - b(r_{m,t})z_{n,t} + p(r_{n,t})z_{m,t}, \\ z_{m,t+1} = z_{m,t} + z + -cz_{m,t} - b(r_{n,t})z_{m,t} + p(r_{m,t})z_{n,t}. \end{cases} \tag{1}$$

In the above equation, z is the ambient stress level in the environment, which we assume is constant over time and common for all agents. The third term represents coping, which is a simple linear function of stress levels. The fourth term represents buffering. Here, buffering by n, i.e. the intensity of stress reduction that n can achieve through the tie to m, is a function of the responsiveness of m, r_m, to n's emotional state. The responsiveness of an agent in turn is determined by the stress in his immediate social environment, so is a function of the mean stress levels of m's neighbours. The final term is spillovers from m to n, which this time is a function of n's responsiveness to m's emotional state.

The social network, or cafeteria interactions take place at the end of the period, after the organization's problem-solving activity has stopped. Social interaction will modify the stress levels resulting from changes in individual workload as described in Section 4.3. If things go well, the cafeteria acts as a cooling device and the joint effect of coping and buffering exceeds the effect of spillovers, yielding overall stress reduction. However, as casual observation suggests, the cafeteria can also be a place in which agents feed each others' stress. The total amount of stress in the system snowballs as agents amplify each others' emotions and eventually all leave the place with an even weaker ability to effectively apply raw energy in the next period. Whether one effect or the other dominates depends on the interaction of the dynamics of emotional contagion in the social network on the one hand, and the fluctuations of workload induced by the stochastic arrival of problems in specific organizational structures on the other hand. A third possibility exists, which is perhaps the most interesting. There are configurations in which multiple stress equilibria are possible in the social network, and the organization structure plays an essential part in selecting either the high or the low stress equilibrium. This has strong implications on the organization's capacity to solve problems and ultimately its performance. We explore them below.

5. Implementation

For convenience we assume the same number of problem types as employees, $N = S = 25$. We assume that a firm's capacity for storing unsolved problems is $C = 40$. Problems initially enter the firm at the rate $\alpha = 5$ per period, until C is reached. At this point new problems enter only to replace exiting, solved problems.

At the beginning of period t, each agent has a raw energy level of 1. His effective energy level is $e_{n,t} = \min\{1, 1/z_{n,t}\}$ where $z_{n,t}$ is his current stress level. During period t, workload-induced stress changes according to changes in the number of problems to which an agent has access. Job stress increases by a multiplicative factor $(1+\rho)^{w_{n,s}}$ when a problem of type s enters the organization, and decreases by a multiplicative factor $1/(1+\rho)^{w_{n,s}}$ when a problem of type s is solved. We set $\rho = 0.35$.

The organizational structures we consider are created as follows. We begin with a perfectly specialized structure, where there is a unique, one-to-one correspondence between problem types and agents. The problem affiliation matrix g of the specialized organization is defined by $g_{n,s} = 1$ for $n = s$, and 0 otherwise. In this case the weighted affiliation matrix w is identical to g.

We build organizations iteratively from that starting structure, by adding ones to each diagonal above the most recently added diagonal. The final structure is the upper triangular matrix (see Figures 1 and 2). Then for iteration i, $0 \leq i \leq N-1$, the affiliation matrices g and w are given by

$$g_{n,s} = \begin{cases} 1 \text{ for } n \leq s \leq \min\{n+i, N\}, \\ 0 \text{ otherwise,} \end{cases} \qquad \text{and} \qquad w_{n,s} = \frac{g_{n,s}}{\sum_n g_{n,s}}.$$

The functions governing social interactions are parametrized as follows:

- Responsiveness: $\exp\{-1.5 \cdot (1/|N_n| \cdot \sum_{k \in N_n} z_k)\}$ where N_n is the neighbourhood of n in the social network;
- Coping: $c \cdot z_n$ where $c = 0.06$;
- Buffering: $z_n \cdot \sqrt{r_m}$;
- Spillovers: $z_m \cdot r_n$
- Ambient stress: $z = 0.45$

So for an interaction between agents n and m, Equations 1 become

$$\left\{ \begin{array}{l} z_{n,t+1} = z_{n,t} + 0.45 - 0.06 z_{n,t} - z_{n,t}\sqrt{r_{m,t}} + z_{m,t} \cdot r_{n,t}, \\ z_{m,t+1} = z_{m,t} + 0.45 - 0.06 z_{m,t} - z_{m,t}\sqrt{r_{n,t}} + z_{n,t} \cdot r_{m,t}. \end{array} \right. \tag{2}$$

To implement the social stress dynamics, sequentially we randomly select 25 links in the social network, and perform one iteration of Equation 2 on each selected link. The stress dynamics of the social interaction in the model are shown in Figure 4.

The figure shows three equilibria: a stable low stress equilibrium at 1.75, an unstable equilibrium at 3.35, and a stable high-stress equilibrium at about 6.8. This implies that there are 4 social regimes: for very low stress levels among the agents, social interaction will tend to increase stress, for very high levels, social interaction will decrease it. For intermediate levels, below the unstable equilibrium social dynamics reduce stress, above it they increase it.[4] This allows the possibility that "unusual" events in the organization, such as a small number of agents receiving many problems in a short time, could tip the organization towards the high stress equilibrium.

To remove as many spurious effects as possible, we initialize agents' energy and stress levels, the social network, and the sequence of problems that firms face to be identical across the 25 organizational structures we examine. Agents are initialized to have identical stress levels, and the organization begins with an empty set of tasks. Thus initial stress levels can be seen as the levels of

[4] In any equilibrium all agents have stress levels equal to the average. We should also note though, that in our implementation, with 25 pairwise interactions per round, the social network does not in general reach the equilibrium. That would take on the order of 200 pairwise interactions.

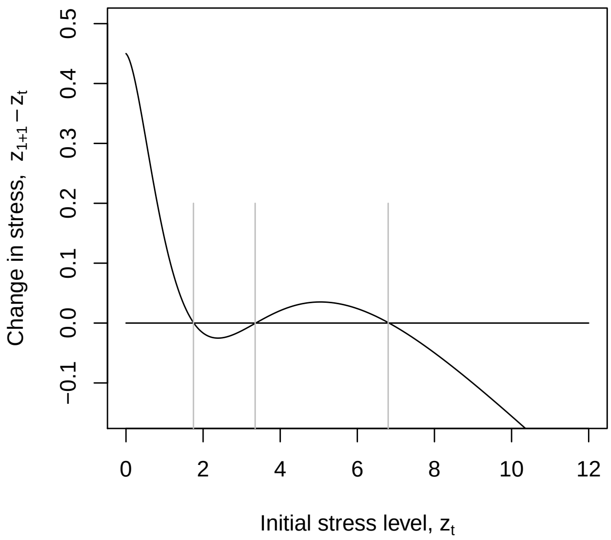

FIGURE 4. Stress dynamics in the social network, showing three equilibria.

stress an agent experiences when his desk is empty of tasks waiting his attention.[5] In this way, it can be seen to capture the stress level inherent in working in this organization: some organizations, for example, may be running largely by routine, and so working there is relatively stress free. Others, by contrast may be in a state of constant turmoil, either through relentless external shocks or through the style (or abilities) of its management. The social stress dynamics have four regimes, determined by the equilibrium stress values. Thus we compare four cases: $z_{n,0} = z_0 \in \{1, 2, 5, 10\}$ for all $n \in \mathbf{N}$. The equilibrium levels of stress as defined by Equations 2 are 1.75, 3.35, and 6.8, and the initial, "empty-desk" stress levels we use falls into the regions defined by those equilibrium values. The social network is constructed as described in Section 4.5 above. The load of each problem in any problem sequence is set equal to $\lambda = 10 \cdot z_0$. We create 75 different sets of starting conditions, and let each of the 25 organizations operate on them for 100 periods. We record, as a measure of performance, the total number of problems solved by the organization over that time, as well as stress levels and a measure of their dispersion.

6. RESULTS

Workload fluctuations and social interaction jointly affect organizational problem-solving performance, with stress acting as the mediating variable. We begin by discussing the two mechanisms at work, before presenting and analyzing their impact of organizational performance.

6.1. **Effects of organizational structure.** The first crucial element is organizational structure, which we vary between pure specialization and a complete

[5]This interpretation ignores any effects of the social network on this "empty-desk" stress level.

hierarchy of managerial responsibility. Absent stress and social interactions, and given our experimental design, organizational structure is the only source of performance variation across different organizations. Specifically, fluctuations in the stack of unsolved problems on an agent's desk do not affect how much energy that agent can effectively apply to problems. Within one replication of the experiment, all organizations, for any depth of managerial responsibility, face the same initial raw energies, the same social network, and the same flows of problems. For all organizations, problems initially come in at a pace that exceeds that of problem solution. Problems thus accumulate in the organization, and the accumulation is evenly spread across individuals. The piles on individual desks grow until the capacity of the organization is reached. Problem solution then changes the distribution of pending problems over individuals.

The effect of changing managerial responsibility on problem-solving activity works essentially through the distribution of workload, which affects the amount of waste in the system by creating what can be called a problem of "problem theft". Waste takes two meanings here. First there is the possibility that a problem is solved with more energy than necessary. This possibility is a source of considerable waste in the original garbage can model, but much less so in the sequential variant we have adopted. Second, there is the possibility that some agents, in a given period, have no problem to act upon when their turn comes. Then their energy is lost, and this constitues the bulk of waste in the present model.

When there is managerial responsibility, that type of inefficiency is due to problem theft. The agents with empty desks have had "their" problems "stolen" by top and middle management who can access virtually any task and participate to problem-solving in a very fluid manner. Problem theft becomes increasingly likely as managerial responsibility deepens. Indeed, as managerial responsibility deepens, more and more agents can apply energy to solving low level problems and it is increasing likely that low level agents, who can only act upon low level problems, have no problem at all to act upon when in a position to do so. Since at the same time top and middle management abandon their "own" tasks, fewer problems are solved in a period. It is worth mentioning that this type of inefficiency can also exist in the specialized organization. There, although problem theft is impossible, the random arrival of problems can leave an agent "empty-desked" and so again his energy is wasted.

In the complete hierarchy of managerial responsibility, top management is responsible for, and involved in virtually all problems (the CEO is responsible for all, and the few agents below are responsible for almost all problems). As a consequence, the piles on top management desks almost always contain C problems, and top management's attention can easily be distracted from the problems where it should be applied (high level problems with few solvers, which only they can solve) to the problems that many can contribute to (low level problems which all can solve). In this world problem theft is frequent, low level problems are systematically solved but seldom by low level workers, and low level workers are often left with empty desks. In short, the organization solves problems, but it does so with significant waste, implying a relatively smaller number of problems solved over a given period of time.

At the other extreme (and still absent stress), the fully specialized organization members solve problems in complete isolation. Problems arrive uniformly across agents, and each agent works on exactly one type of problem, where he repeatedly applies energy. So on average the piles on agents' desks consist of C/N problems. There can be waste as well, but only due to stochastic fluctuations in problem arrival. The desk of an agent remains empty because there is no problem of "his type" in the morning delivery, and not because "his problems" were stolen and fixed by managers. In addition, as we consider problems of identical loads, there is no possibility for an agent to leave a problem already advanced and switch to a different problem with smaller load just entering the agent's stack. Once a problem has been worked on, it is worked on by the agent until it leaves the system. Unlike the hierarchy, there is no possibility that an agent is distracted from the problems where he is indispensable. But with the impossibility of problem theft there is also no possibility to pool agents' energies to finish off a problem more rapidly, and a higher probability of facing an empty desk for top and middle management.

We now clearly see the effect of managerial responsibility on workload: the system moves from a configuration of identically shared work, on average C/N problems on any agent's desk, to a strongly asymmetric allocation of desk piles, in which some agents (the bottom levels ones) often have empty desks whereas the CEO has always C problems in sight, and other high level managers also have large numbers of unsolved problems on their desks.

Between these two extremes, it is possible that an organization with some intermediate degree of managerial responsibility retains the strength of the polar cases, having both a low inclination towards problem theft, and enough problem-sharing to avoid the empty desk situation.

6.2. **Effects of stress and social interaction.** We add now stress on top of the previous building block of the model. In addition to the effect that managerial responsibility exerts on problem solving activity via the distribution of workload, there is a strong effect of stress on efficient energy levels, and thus on the entire problem-solving capacity of the system. Now, fluctuations in the stack of unsolved problems on an agent's desk affects how much energy that agent can effectively apply to problems.

In the complete hierarchy of managerial responsibility, stress accumulates on top management as the piles on their desks grow. As a result energy available to top management falls dramatically while energy available to the low levels workers is roughly unchanged. Again, low level problems are solved, while high level problems, addressable only by top management, accumulate. However, as stressed management has less effective energy to devote to solving low level problems, problem theft is somewhat alleviated. Low level workers face less often desks emptied by hasty managers, but they still do. Here, the role played by the weighted affiliation matrix w (which was introduced in Section 4.3) is easily seen. It avoids that all problems are equally stress-inducing to all their potential contributors, and thus mitigates the effects of stress, while not eliminating them completely: top management remains at higher stress level than bottom level workers in the complete hierarchy.

In the specialized organization, stress does not affect the stochastic entry of problems. However, by slowing down problem-solving (less effective energy becomes available) it reduces the likelihood that agents are seated at empty desks. So less waste but also fewer problems solved over the firm's horizon in the presence of stress.

Finally the social network is introduced, and with it the possibility for agents to lower job stress by buffering (some of) it in social interactions. However, social interaction is both capable of soothing, undoing the emotional condition created by problem accumulation, and of amplifying that condition. Which effect dominates depends on which "empty-desk" stress level environment we are in. In a very high stress environments ($z_0 = 10$), social interactions will tend to reduce stress levels. In very low stress environments, ($z_0 = 1$) the reverse is true. In the intermediate cases, ($z_0 \in \{2, 5\}$) it will depend on the organizational structure.

6.3. **Organizational performance.** Figure 5 displays the problem-solving performance of all 15 organizations[6] over 75 replications, in the three configurations of no stress (and no social effects), stress and no social effects, and the combination of stress and social interactions. We show four different environments, parametrized by the stress level that obtains when an agent has an empty desk (ignoring social interaction effects). Differences in baseline stress might correspond to organizations facing more or less turbulent environments with higher levels of uncertainty inducing more stress. Alternatively, differences in baseline stress could also capture differences in corporate culture and beliefs of management about the merits of strain.

There are several observations to be made from this figure.

First, there is an interior optimal amount of managerial responsibility in all configurations and for all levels of baseline stress. The fully specialized organization is inefficient in terms of problem-solving. So is deepest managerial responsibility, but to a lesser extent. Specialized organizations always perform worse than any other organization structure: the absence of problem sharing turns out to be very deleterious to performance.

Second, the extent to which social interactions can restore effective energy levels depends strongly on the level of baseline stress. An organization with low baseline stress (lower than the low stress equilibrium of the social network, here $z_0 = 1$) essentially needs no cafeteria. Social interactions there are dominated by the negative effects of spillovers: although the fluctuations in the workload are not inducing much stress, the little there is gets amplified in the cafeteria, resulting in lower productivity of workers after a stay there. The organization with a cafeteria is always outperformed by that without it.

The mirror image of that situation obtains with high baseline stress, $z_0 = 10$.. Social interactions there have a soothing effect. Stress levels go down and energy is applied more efficiently to problems. The organization is able to benefit from social interactions, provided it creates the conditions for them to take place by having a cafeteria.

[6]We display only 15 organizations, since the results on the organizations with deeper managerial hierarchy are identical to the final one displayed.

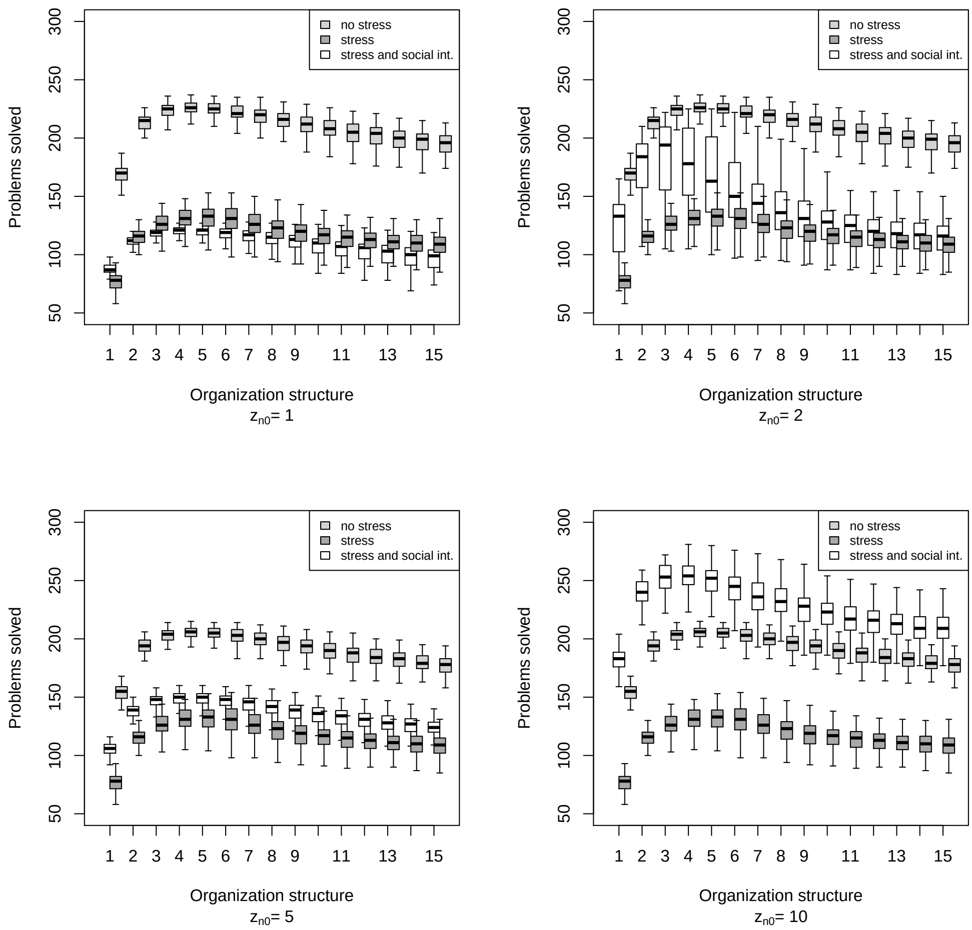

FIGURE 5. Problems solved over the 100-period history, for different stress dynamics, in each of four settings.

The case of medium-high baseline stress (between the unstable and the high stress equilibria, $z_0 = 5$) is similar to the first case of low baseline stress. Interactions in the cafeteria push agents up towards the high stress equilibrium, resulting in a smaller number of problems solved due to less energy applicable.

The most interesting configuration is the fourth one, of medium-low baseline stress, $z_{n,0} = 2$, where the baseline stress level lies between the unstable and the low equilibrium stress levels. In this configuration social interaction is capable in principle of countering the effects of workload, keeping stress low enough. In terms of central tendencies, social interactions cause an improvement in performance for all organization types, and this is most pronounced for relatively specialized organization structures. However, the height of the boxes and their whiskers indicate that there is a wide variation around this central tendency. Contrasting the social interaction case (white boxes) with the stress but no social interaction case (dark grey boxes) indicates that the presence of social interaction in a specialized organization can have very different effects, depending on the social network and the sequence of problem arrivals. While the social interaction case always involves more variability over the 75 replications, the extent of it falls significantly as managerial responsibility becomes deeper. Social interaction increases the median performance and performance variability for specialized organizations. For organizations with deep managerial responsibility social interaction has only a small positive effect of median performance but does imply a greater performance variability.

What drives the variation in performance is the fact that within one organization (and one particular run of the system) the population of agents can in some circumstances have very different stress levels. The social dynamics exhibit multiple equilibria, and different (numbers of) agents can be attracted to different equilibria. Figure 6 displays the number of agents in each organization who are in a high stress state in period 100 (stress level higher than the unstable equilibrium level). Again the boxes show the distribution of the number of high-stress agents over the 75 replications.

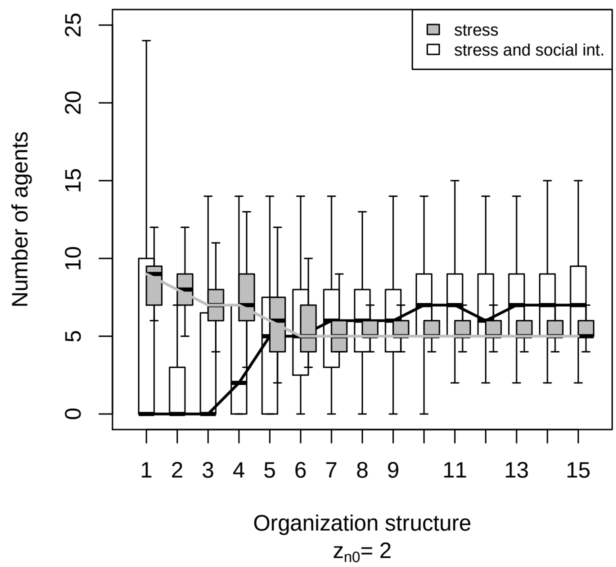

Figure 6. Number of agents with high levels of stress at the end of 100 periods, defined as stress levels above the unstable equilibrium of the social dynamics ($z_{n,100} > 3.35$).

First, we observe that in the case with stress but no social interaction (grey boxes) the median number of agents in a high-stress state falls as managerial responsibility deepens, and the variation around that central tendency does not change significantly. By contrast, in the case including social interaction (white boxes), we see that in the most specialized organization, sometimes all of the agents are tipped into a high stress state. But more commonly none is: the median level for relatively specialized organizations, is zero. This rises as managerial responsibility deepens. The ability of social interaction to calm agents allows the specialized organization to achieve a much lower overall stress level than would otherwise be the case, generally speaking, though for less specialized organizations social interactions seem to raise the median stress level.

Additionally, throughout the space of organization structures, social interactions increase dramatically the variation around the central tendency. There is a much higher variance in the number of agents with high stress than there is absent social interaction. This is especially so for the extreme specialized organization.

Specialized organizations have a structure that permits some (and possibly many) of its agents to reach a low-stress state through social interaction. When this happens these structures succeed in solving almost as many problems as can be solved when there is no workplace stress (compare the white boxes with the light grey boxes in Figure 5, top right panel). This arises from the relative isolation of the work environment. Agents who are lucky with the sequence of problems are able to keep up, and so work does not drive their stress levels high. At the same time, because of the specialized structure, they do not share problems with their "unlucky" neighbours in the organization, and so there is no contagion of stress through the workplace.[7] By contrast, in organizations with complete managerial control, many more agents reach the high-stress equilibrium. Additionally, those agents who find a low stress state would have done so even in the absence of a cafeteria, through the reallocation of workload as problems are solved, and the distribution of pending problems changes. Here, top and middle management remain highly stressed, and organizational performance tracks that of the organization not having a cafeteria.

7. Discussion

We have been interested in the interaction between organization structures and social structures in terms of their effects on stress dynamics and ultimately organizational performance. We have not explored the space of possible social network structures, asking instead how, in the context of a given social structure, changes in organizational structure affect organizational performance. Stress is the mediating variable here.

Moving from a specialized organization where responsibility for problem is highly compartmentalized to one in which managerial responsibility extends some way down the organization we observe several changes in the structure and dynamics. First, problem sharing becomes more and more possible as the number of agents able to address a particular problem type grows. This clearly provides an avenue of relief for any agent whose pending tasks are increasing: others may be able to help, and so prevent the spiral in which tasks pile up, increasing stress, decreasing effective energy, making problem solution more difficult, which means that tasks pile up faster. If several agents can address a problem type, it is possible that this cycle can be broken.

Second, at the same time, the structure which permits job sharing also implies that any new task that enters affects more than one agent. The formalism we use to

[7]Because the social structure is likely to reflect the organization structure at least to some extent, agents close in the social structure are likely to be close in the organization structure if it is not too specialized. This implies that if an agent receives a sudden deluge of problems, it is likely that his close neighbours in the social structure are also participating in at least some of those problems (and similarly if an agent enjoys a quiet period so will his social neighbours). Thus social interaction can amplify changes in stress that agents experience through the work environment.

share tasks among individuals implies that the more hierarchical the organization, the less effect one new task has on total stress in the organization. In aggregate, hierarchies are good for "keeping stress down" — the more people share a new task, the less total stress increases.[8] However, the relationship between stress and energy is non-linear, and given our formalisms, total effective energy in the organization decreases more the more people share a task. Thus the structure that involves more agents in any given task has both positive and negative effects.

Third, when agents can share tasks, this can create clusters of high or low stress agents. Since the social network to some extent reflects the organization structure, agents close together in one will be close together in the other in general. Thus if a cluster of agents suddenly have a large influx of tasks, their job stress will rise. They carry that (as a group) into the social interaction, and this can cause a spiral where the social interaction pushes the stress of the group higher, making task completion more difficult, etcetera. Of course a virtuous circle is also a possibility. Thus we might expect that clusters of high or low stress agents will emerge. The size of these clusters is likely to increase sharply as we move away from the perfectly specialized organization, but then increase much more slowly as we approach the hierarchical organization, since the larger the group of agents who can address a given problem the lower the effects of stress from the arrival of that problem type.

Fourth, moving towards deeper managerial responsibility creates some agents who have more responsibilities than others. This implies that there will be agents who routinely have more tasks on their desks than others. These agents can easily be bounced into a high stress state, with consequent negative effects on their energy levels. What this means is that the tasks for which they are the sole (or almost sole) person responsible will never be completed. They have little energy, so their tasks receive at most small amounts of energy per period. Other tasks with many participants, typically receive more input per period and so are closer to completion. The energy allocation rule indicates that those close to completion should receive attention, so any tasks which can be addressed by only a few agents never gets completed. And much energy is wasted by low level agents who have no problem to which they can apply their attention and energy.

8. Conclusion

The members of any organization play at least two roles: they are workings fulfilling to a greater or lesser extent the tasks of their organization; and they are engaged in social interactions with colleagues, friends and relatives. These roles intersect, and can interact. In this paper we have presented a model in which these two roles are included, and interact by affecting agents' stress levels, which in turn, affect their ability to perform at work. The introduction of stress into a model of organizations adds a dimension that, while often implicit in discussions, is seldom modelled.

Issues of worker stress are implicit in discussions of organizations "cutting fat". This has been a common management strategy as a way of stream-lining organizations to make them more productive. And of course it is a particularly popular

[8]This is an average result, though, assuming that all agents have the same stress level when the task arrives.

refrain of politicians on the electoral campaign trail. Fat, in an organization is often thought to be present when employees spend less than their entire working day engaged in task-completion or problem-solving. Social interactions in the workplace are often seen as evidence of the kind of fat that can be safely cut. What the model here argues is that such a line can be quite wrong. It is well-established both that social interactions can affect group and individual stress levels, and that stress levels affect productivity. Thus cutting fat to the point of eliminating social interactions can have unexpected effects on overall production efficiency of the organization. What our results suggest is that under different environmental stress levels, social interactions are good or bad for productivity. When the organization has a high background stress level (either because its external environment is unstable, or because management style or activity induces stress) then social interaction can be useful and sometimes very useful in mitigating those effects and improving productivity. In a moderately stressful environment, whether or not social interactions help or hurt aggregate performance depends on the organizational structure. For specialized organizations they do; for organizations with deep managerial responsibility, they seem not to. There, slack can again safely be reduced. Finally, when the organization operates with a low background stress level (either because its global environment is stable or because management is effective in eliminating stressors) then social interaction can be safely reduced. In fact, in an extremely calm environment, social interactions increase stress, and might so reduce productivity.

These results are based on a particular assumption regarding stress and productivity, namely that increases in an individual's stress reduces his productivity. One must interpret that with some caution, on account of what is know as the Yerkes-Dodson law. This empirical generalization states that there is an inverted-U relationship between stimulus (which can be interpreted as stress) and performance. It could be possible that in the very low environmental stress case, workers are on the left side of this relationship, and so a little increase in stress, induced in the model through social interactions, would be good for performance. This is not included in the model since it seems unlikely that it would apply to many organizations. It is something that could usefully be explored further however.

A second issue that could be further explored is the cost of social interactions. In the model, there is no cost — social interaction does not take time away from work. Some interactions do, and some do not reduce the time agents have available to address their tasks. Introducing this into the model could change the dynamics, and the effects of social interaction on productivity. It would also permit a further more detailed exploration of the optimal amount of social interaction for given organizational structures under different environmental stress conditions.

Finally, our analysis has focused on aggregate performance. But management, while seeing aggregate performance as its final goal, could also be interested in individual performance. Which agents are completing many tasks; which are completing few? Here there is likely to be a strong interaction between the architectures of the two networks. Where an agent is located in the social network determines who he interacts with, whose stress he buffers and whose stress spills over to him. Where an agent is located in the organizational network determines with whom he shares tasks, and so whose workload, and therefore stress affects him. The first question here is which positions in these networks lead to high and low performance. The second, and more subtle question is whether by manipulating the relationship between the organization structure and the social network, individual, and thus aggregate, performance can be improved.

Social interactions are known to be part of healthy organizations. Stress levels are known to affect individuals' performance. The combination of these two ideas can generate interesting and important changes in an organization's ability to function effectively in achieving its goals. There is considerable scope to further develop the relationship between these two, coevolving facets of an organization and in so doing to better understand how an agent's multiplex relationships interact.

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